3D EXTRACTION METHODS

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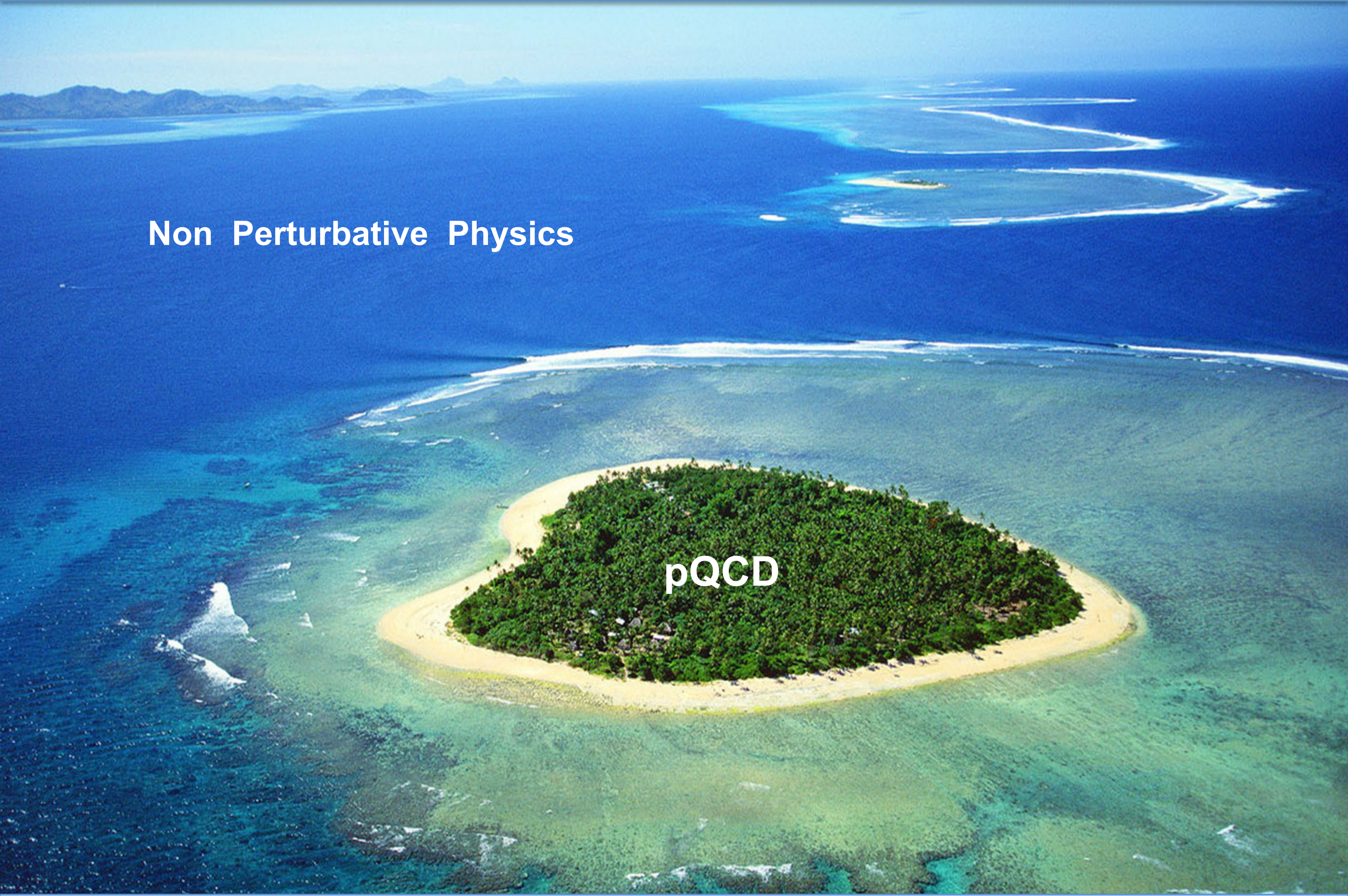
Fragmentation Functions 2018
February 21, 2018 Stresa

The QCD View



TMDs Landscape

Phenomenology:

gather active dynamic mechanisms
spin-orbit, short range correlations, nuclear p_T broadening

make educated guesses on parton behavior
average transverse momentum, orbital motion

is the naïve interpretation of the observable sensible ?

Predictive Power (applicability as for collinear PDFs):

rigorous treatment, i.e. for tensor charge extraction, exploiting

universality

evolution well defined but not necessarily under control at medium-low energy

scale dependence should improve with next-to-leading orders, as for k-factor in DY
can the non perturbative parameters be constrained at B-factories ?

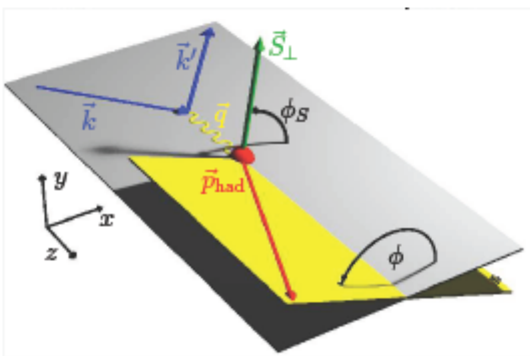
DIS Cross-Section

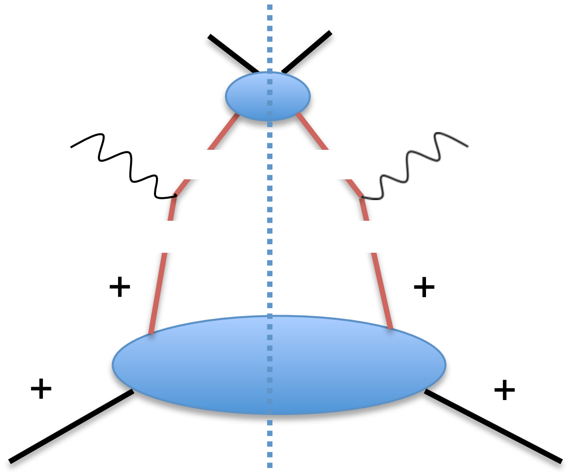
$$\frac{d^6\sigma}{dx\,dQ^2\,dz\,dP_h\,d\phi\,d\phi_S} \overset{LT}{\propto} \left[F_{UU} + \varepsilon\cos(2\phi)F_{UU}^{\cos(2\phi)}\right] + S_L\left[\varepsilon\sin(2\phi)F_{UL}^{\sin(2\phi)}\right]$$

$$+ S_T\left[\sin(\phi-\phi_S)F_{UT}^{\sin(\phi-\phi_S)} + \varepsilon\sin(\phi+\phi_S)F_{UT}^{\sin(\phi+\phi_S)} + \varepsilon\sin(3\phi-\phi_S)F_{UT}^{\sin(3\phi-\phi_S)}\right]$$

Multi-D in SFs

$$+ S_L\lambda_e\left[\sqrt{1-\varepsilon^2}\,F_{LL}\right] + S_T\lambda_e\left[\sqrt{1-\varepsilon^2}\cos(\phi-\phi_S)F_{LT}^{\cos(\phi-\phi_S)}\right] + O\left(\frac{1}{Q}\right)$$





Quark fragmentation

TMD Factorization holds for $p_T << Q$

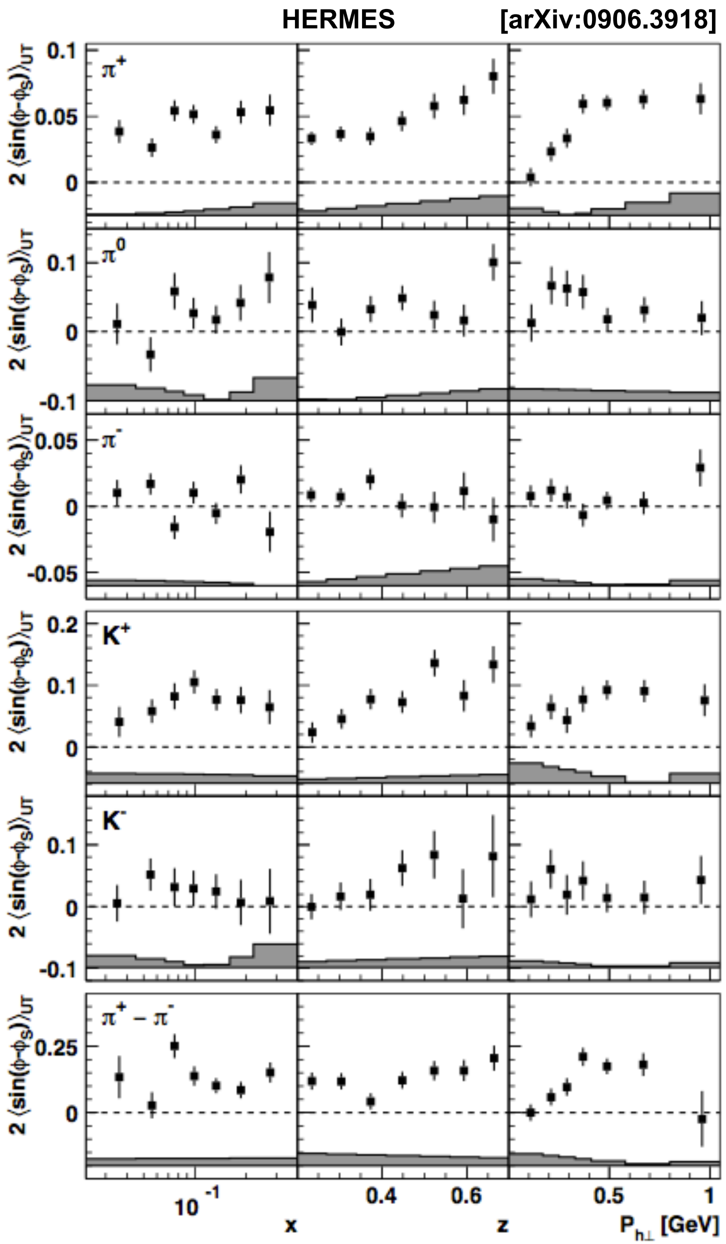
Quark parton distribution

Wide kinematic coverage is needed to resolve the convolution

Multi-D in kinematics

$$F_{UU} = f \otimes D = x\sum_q e_q^2 \int d^2p_T\,d^2k_T\;\; \delta^{(2)}(\mathbf{P}_{h\perp} - z\mathbf{k}_T - \mathbf{p}_T)\;\, w(\mathbf{k}_T,\mathbf{p}_T)\;\, f^q(x,k_T^2)\;\, D^q(z,p_T^2)$$

Acceptance Effects



In binned asymmetries acceptance does not necessarily cancel

$$A_{LL}(\bar{\Omega}) = \frac{\sigma_{LL}(\bar{\Omega})}{\sigma_{UU}(\bar{\Omega})} \neq \frac{\int \varepsilon(\Omega) A(\Omega) F_{LL}(\Omega) d\Omega}{\int \varepsilon(\Omega) B(\Omega) F_{UU}(\Omega) d\Omega}$$

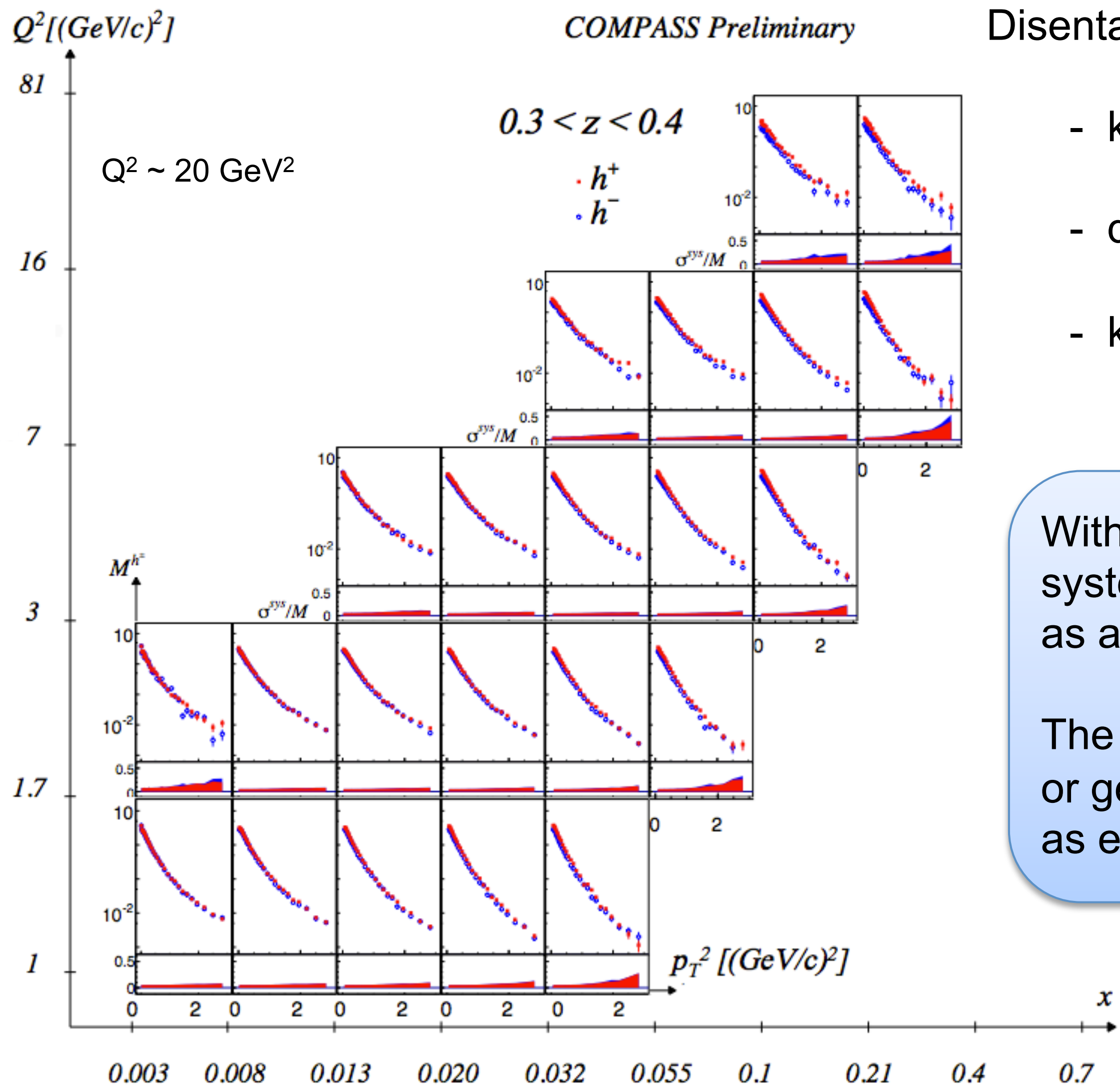
WARNINGs:

- Phenomenological fits buy such an underline approximation

- Integral may folds-in unwanted contributions

- Even a collinear analysis needs an un-integrated analysis to control systematics in case of non-uniform azimuthal acceptance

Multi-D Investigation



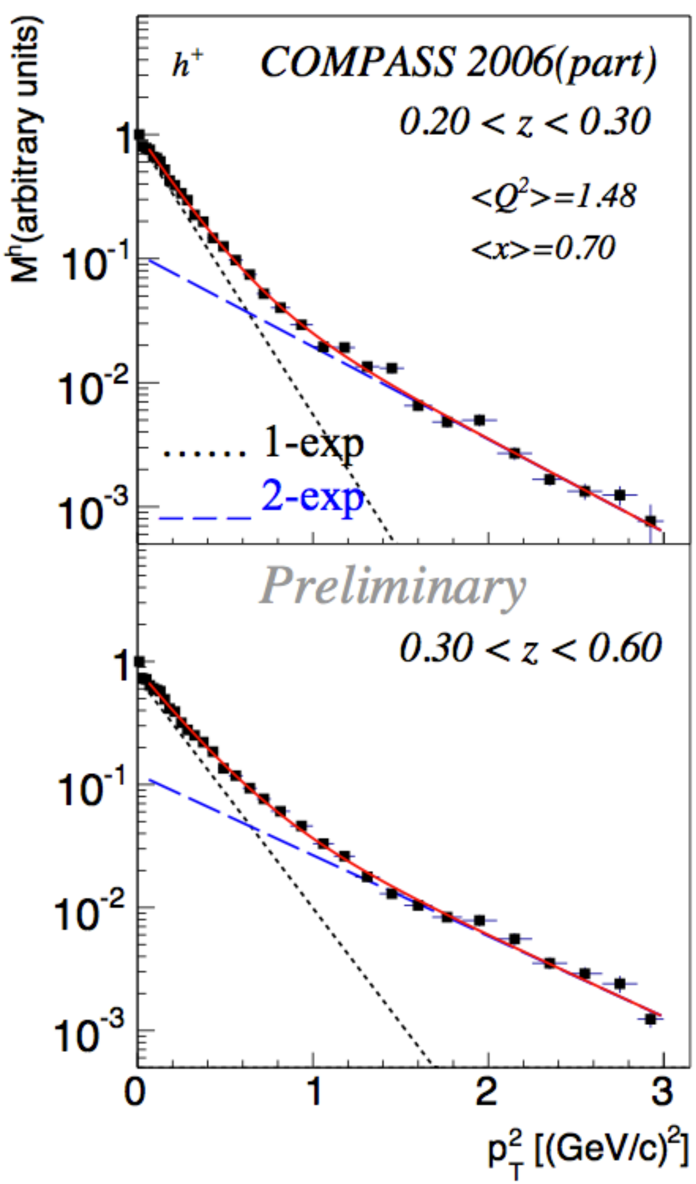
Disentanglement

- kinematic dependences
- dynamical regimes (twist, perturbative)
- kinematical dilutions

With such a precision systematics is highly not-trivial as any small effect matters

The typical values (i.e. average Q^2), or general behaviors are misleading as each corner matters in its own

$P_{h\perp}$ Accessible range



Not anymore in the TMDs regime

$$\frac{p_T^2}{Q^2} \sim O(1)$$

Relevant for matching with high-p_T perturbative calculations

Do we ever rich the perturbative regime ?

What can we learn/improve about soft-gluon resummation ?

Is the Y term dominating everywhere at fixed target energies ?

Gaussian ansatz quandary is the simplified version of the matching problem

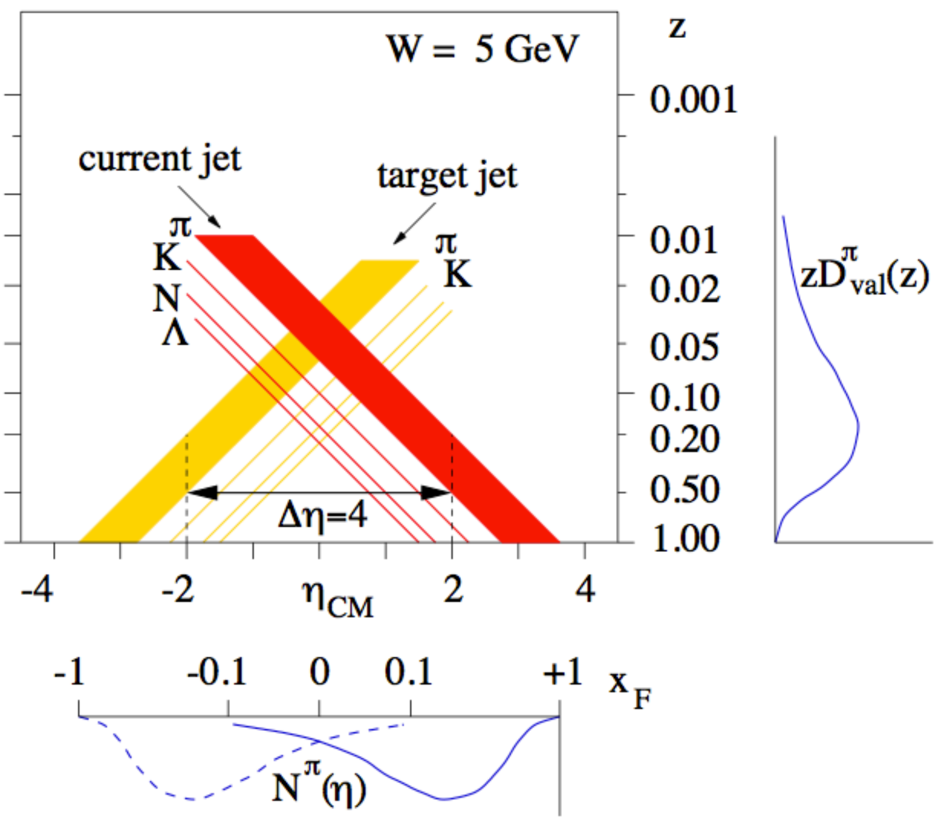
Target vs Current Fragmentation

Or forward vs backward hemisphere fragmentation

Can thrust be used to define a e+e- x_{F}/rapidity indicator ?

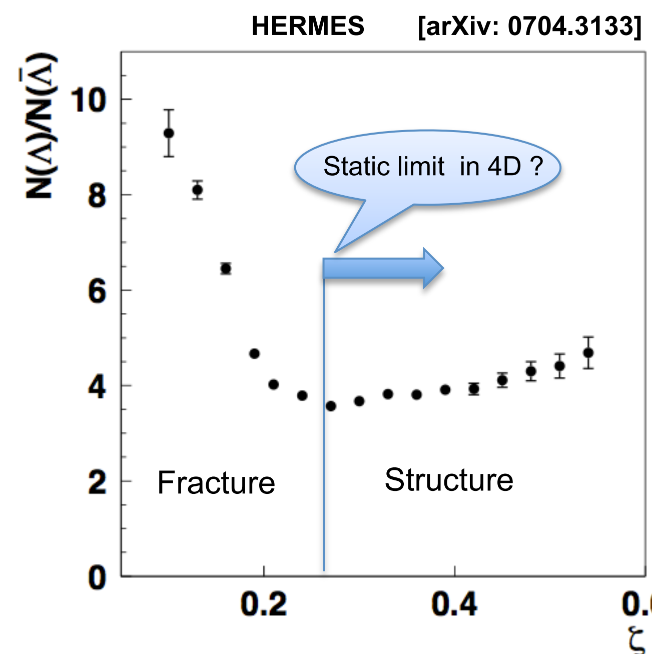
Berger criterion

[P.J. Mulders hep-ph/0010199]



Empirical criterion

Inclusive $\Lambda/\bar{\Lambda}$ yield at W~5 GeV



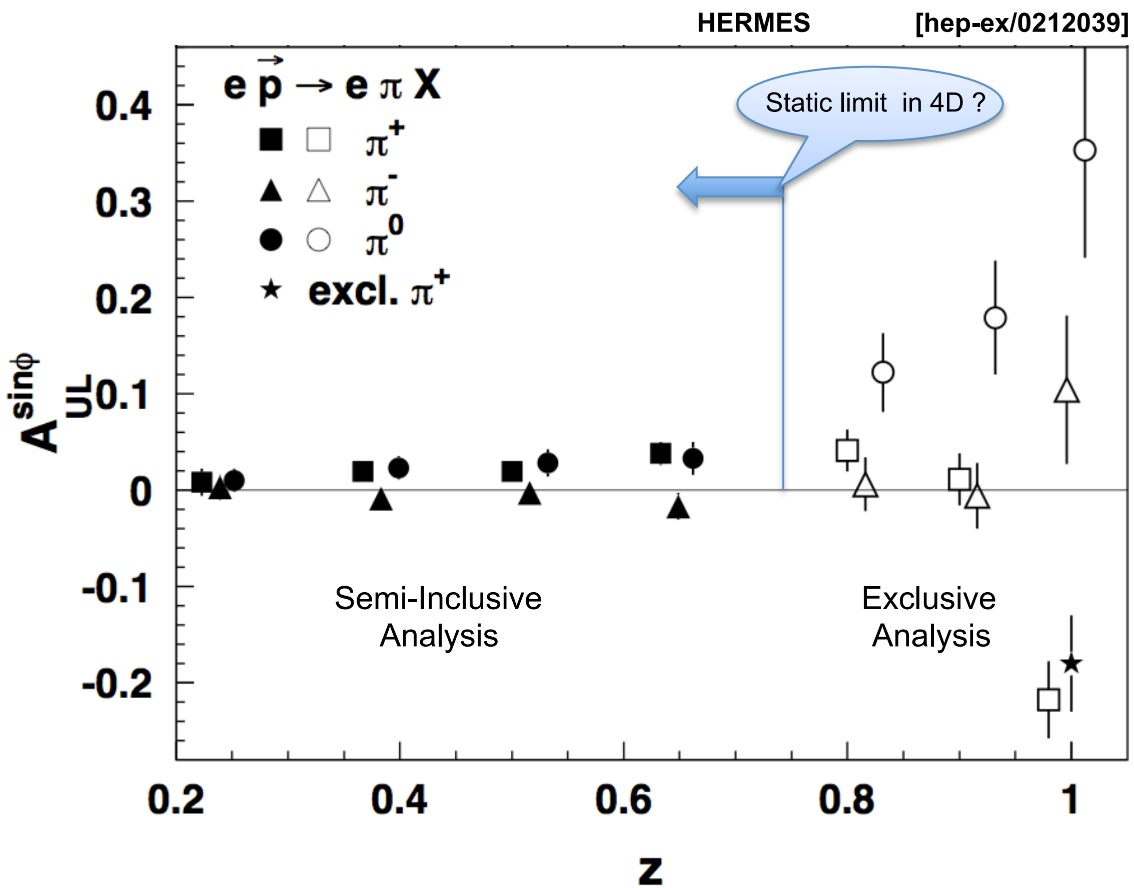
$$\zeta \equiv (E_\Lambda + p_{z\Lambda})/(E_e + p_e)$$

Highly correlated to x_F

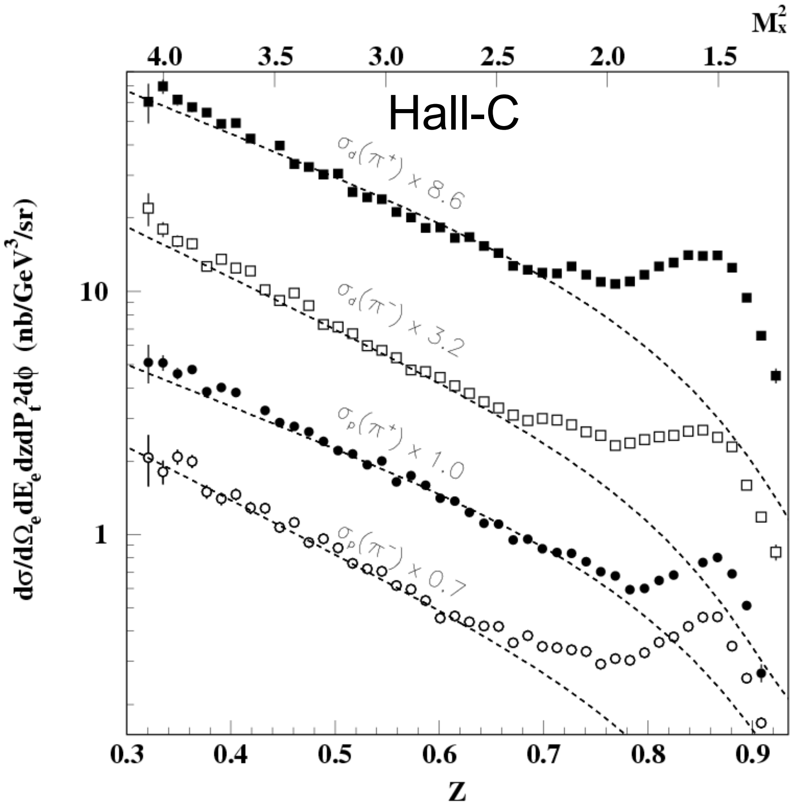
Semi-Inclusive vs Exclusive

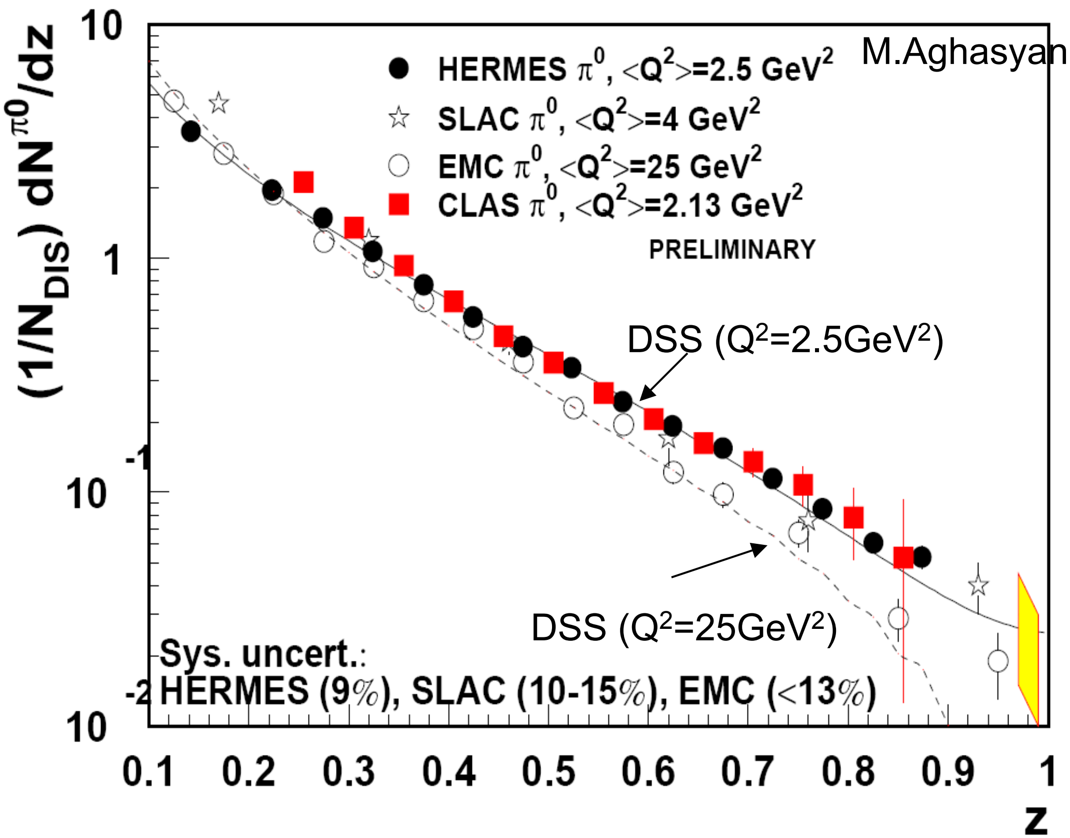
When the exclusive is no more part of the semi-inclusive ?

Is the cross-contamination due to i.e. radiative effects under control ?



JLab Pion Multiplicities (@ 6 GeV)

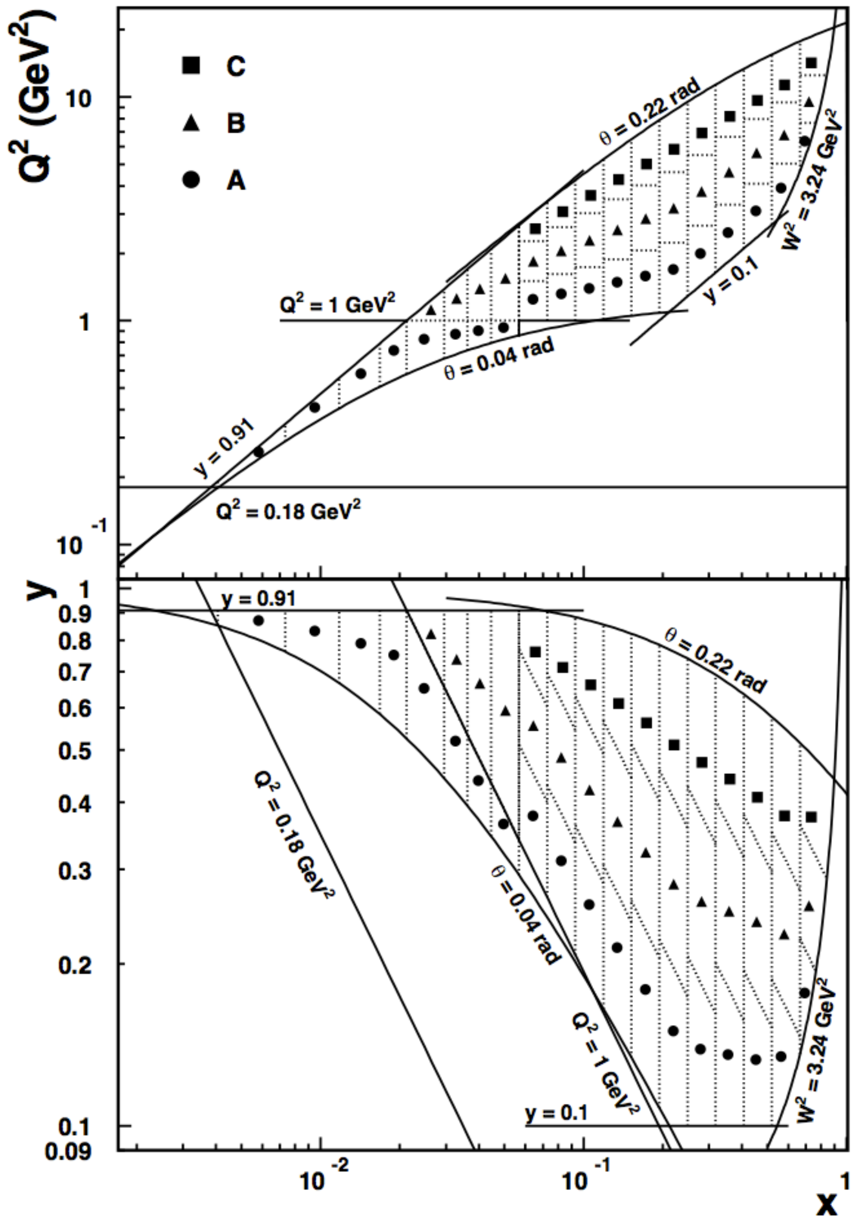




ep→e'πX

$\pi^{+/-}$ multiplicities at large z diverge from SIDIS predictions
π^0 multiplicities less affected by higher twists
0.4<z<0.7 kinematical range, where higher twists are expected to be small

Event Migration and Moment X-talk



What about event migration ?

- define bins larger than resolution

but keep in mind non-linearities!!!

$$\frac{dx}{x} \propto \frac{1}{y}\frac{dp}{p}$$

- radiative effects change the kinematics and introduce a x-talk between moments

a full knowledge of the hadronic tensor is in principle required

- acceptance may fold-in

unwanted (not fully integrated out) or un-physical moments

No real difference with ISR x acceptance

Event Migration and Moment X-talk

Event migration implies a reshuffling, not a loss of information.

unfolding smearing and radiative effects introduces a statistical correlation
the full statistical power of data is restored using the covariance matrix

$$Y_{Exp} = M\, Y_{Born} + Y_{Back}$$

$$Y_{Born} = M^{-1}\,(Y_{exp} - Y_{Back})$$

Detector model ⊗ Physics radiation
(known) (in principle known)

Un tested physics
(model dependence)

Longitudinal Cross-section

$$\frac{d^5\sigma^{ep\to e'hX}}{dx\,dy\,dz\,d\phi\,dP_{h\perp}^2} \propto \{F_{UU,T} + \varepsilon F_{UU,L} + \sqrt{2\varepsilon(1+\varepsilon)}\cos(\phi)F_{UU}^{\cos(\phi)} + \varepsilon \cos(2\phi)F_{UU}^{\cos(2\phi)}\}$$

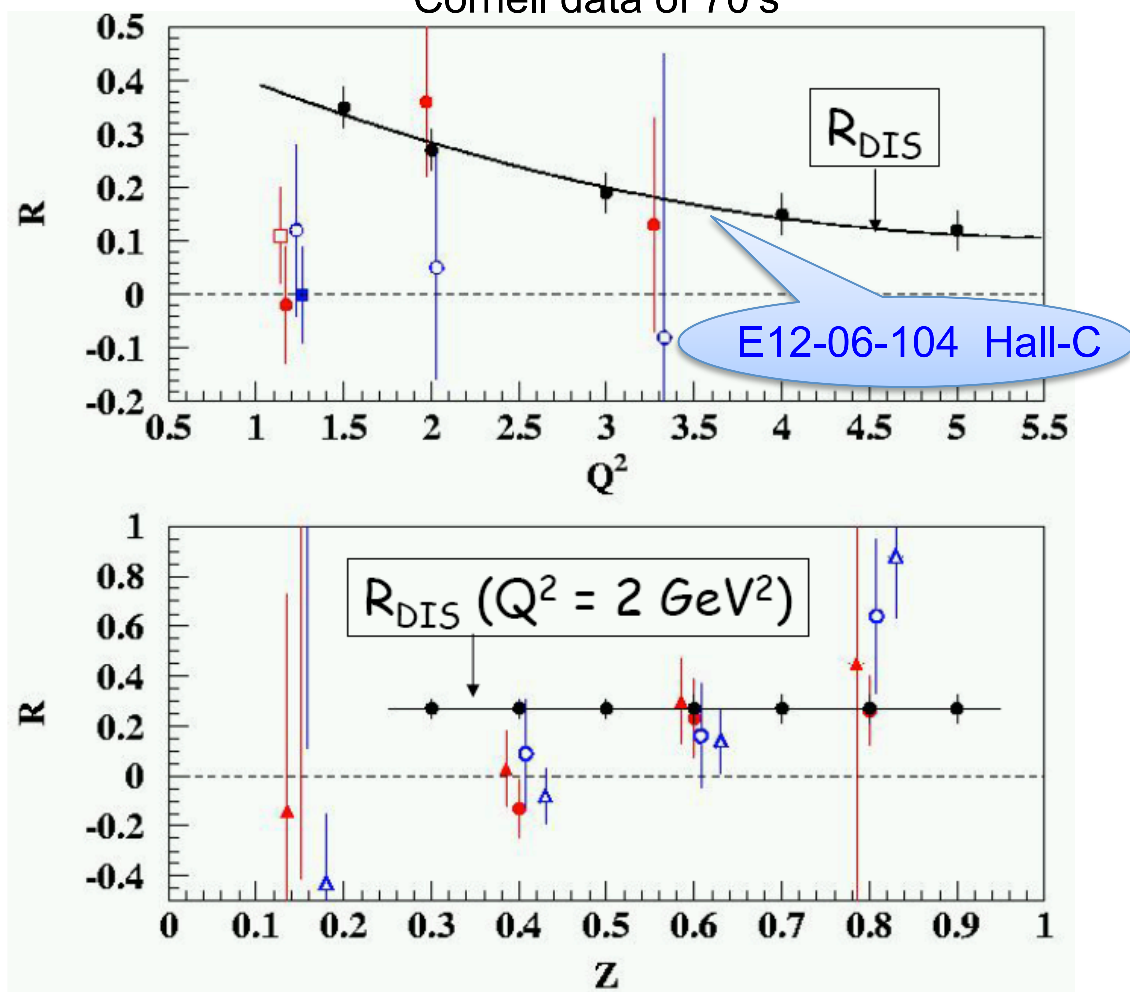
Knowledge on R = σ_L/σ_T

in SIDIS is non-existing!

To be accounted in any TMD asymmetry interpretation

- $R_{DIS} \to 0$ at $Q^2 \to \infty$ due to scattering off spin-½ quarks
- R_{DIS} sensitive to gluon and higher-twist effects
- $R_{SIDIS}(z,pT)$ = un-integrated R_{DIS}

Cornell data of 70's

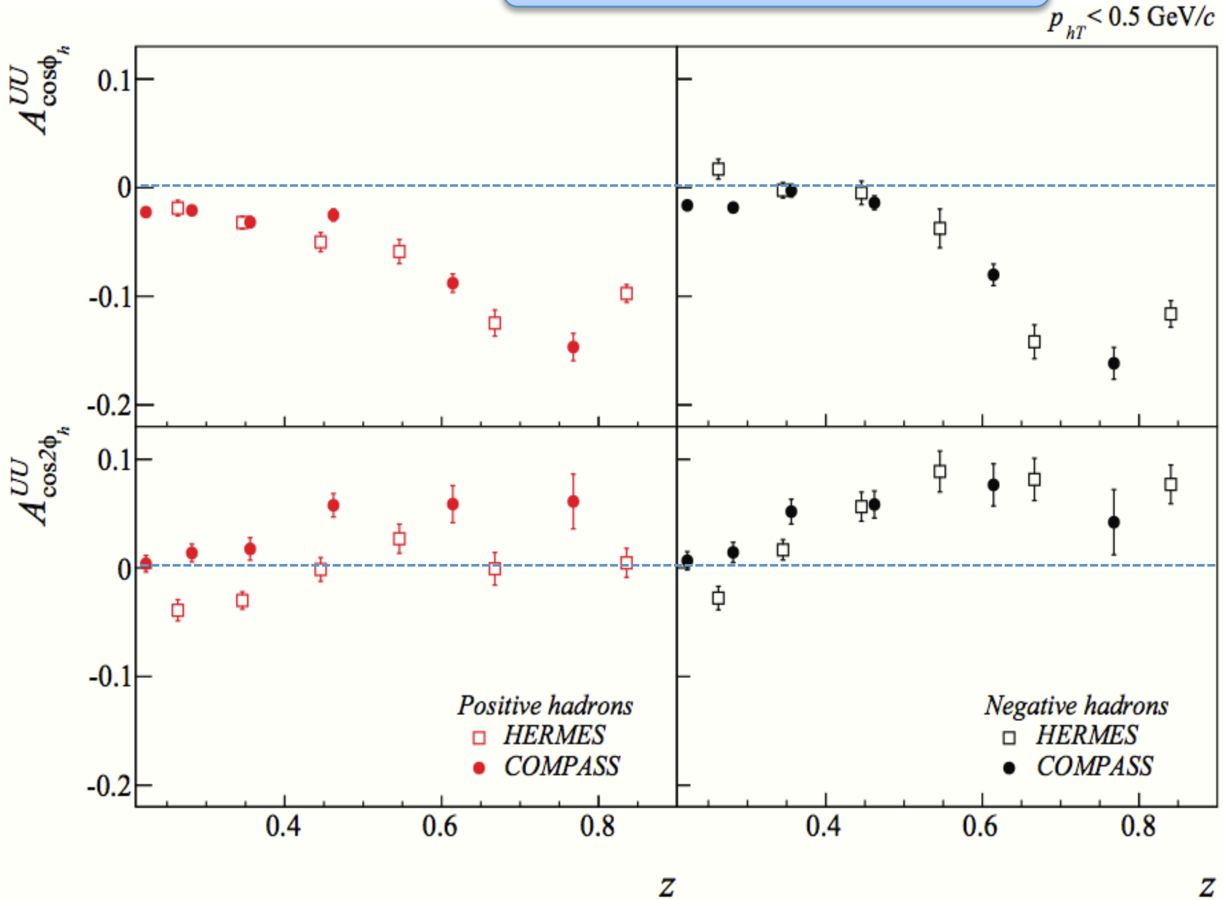


Azimuthal Modulations of F_{UU}

$$\frac{d^5\sigma^{ep\to e'hX}}{dx\,dy\,dz\,d\phi\,dP^2_{h\perp}} \propto \{F_{UU,T} + \varepsilon F_{UU,L} + \sqrt{2\varepsilon(1+\varepsilon)}\cos(\phi)F_{UU}^{\cos(\phi)} + \varepsilon\,\mathrm{s}\cos(2\phi)F_{UU}^{\cos(2\phi)}\}$$

Intrinsic k_T Cahn kinematical effect

$$F_{UU}^{\cos\phi} \propto [f_1 D_1 + \ldots]/Q$$



Hall-B Mission

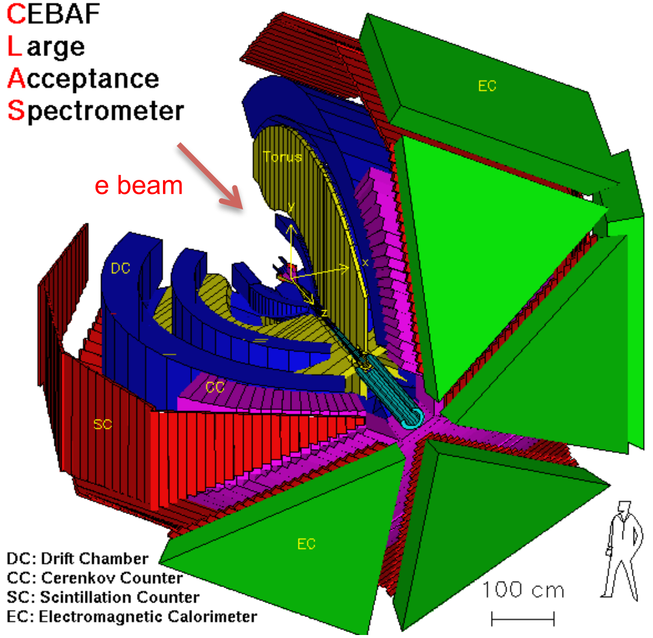
Comprehensive measurements based on : High luminosity up to 10^{35} cm^{-2} s^{-1}
Large acceptance (current & target fragmentation)
Polarized beam and targets
Multi-particle final state measurements

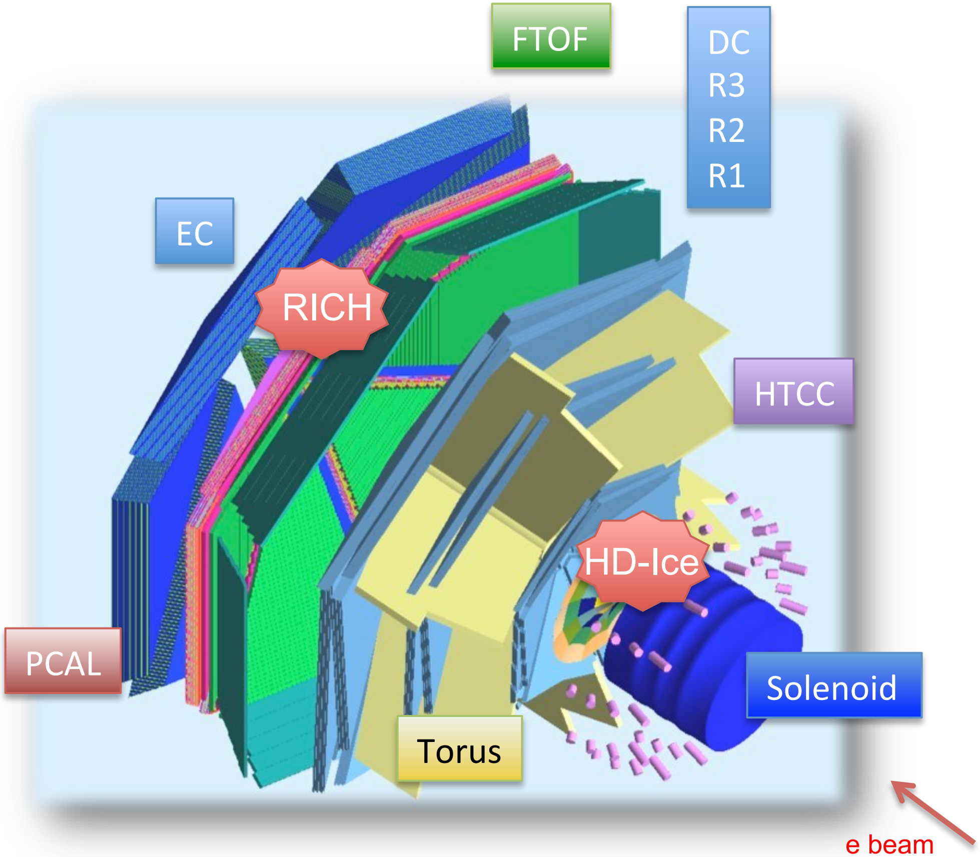
6 GeV

12 GeV

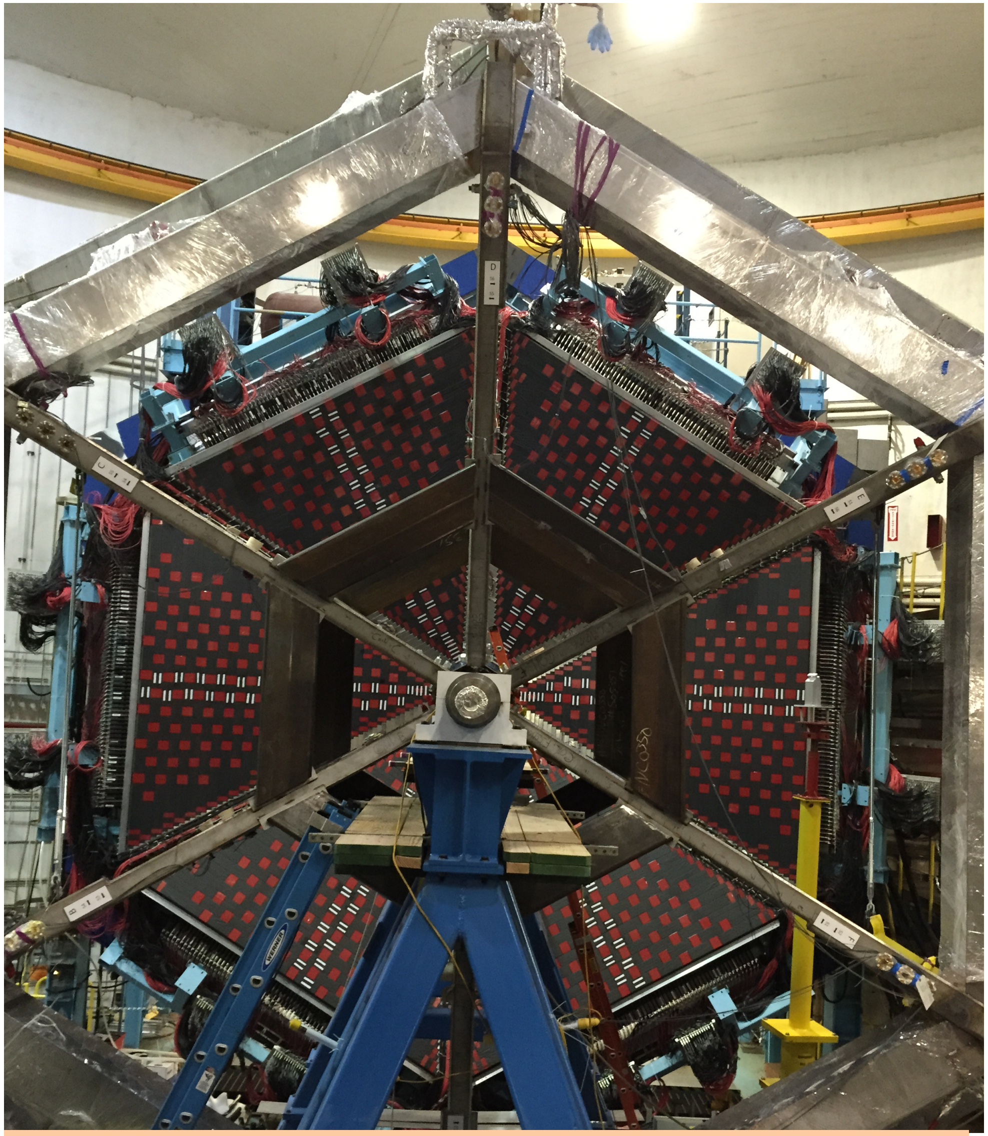
NIM A503, 513 (2003)

CEBAF
Large
Acceptance
Spectrometer

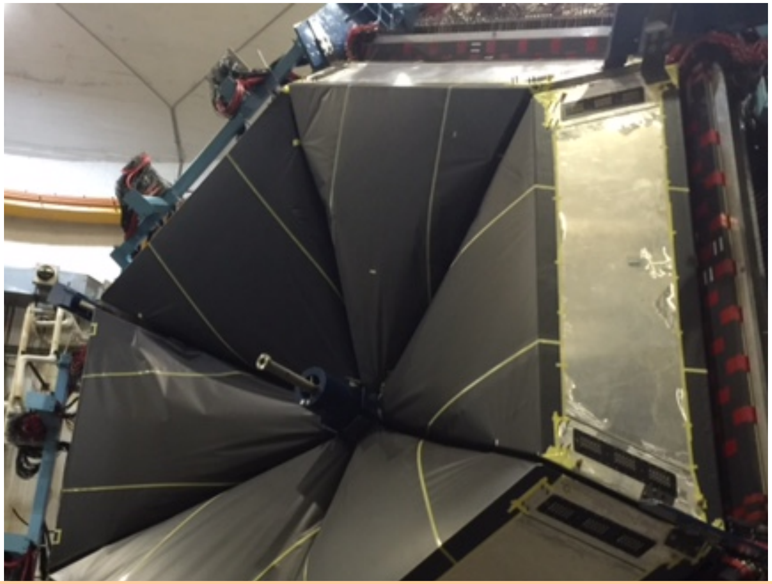




CLAS12 Forward Detector (Current Region)



Torus + Time-of-Flight Wall (Hadron ID)

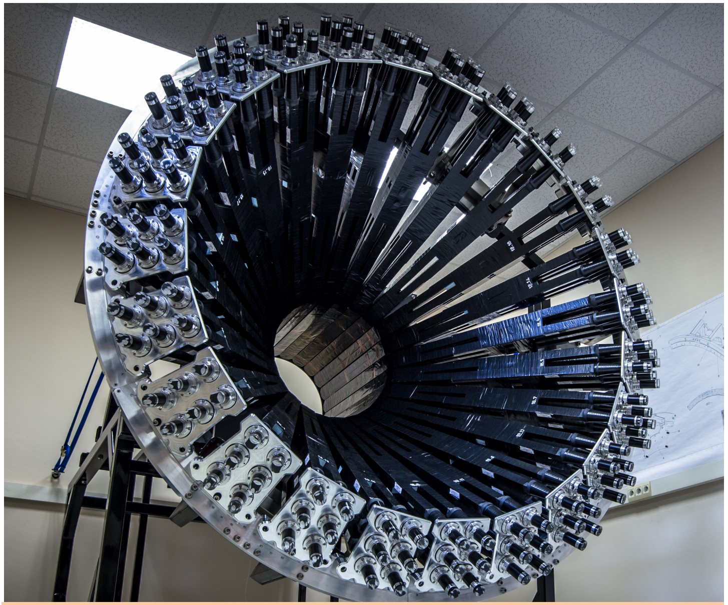


Low-Threshold Gas Cherenkov (pion ID)

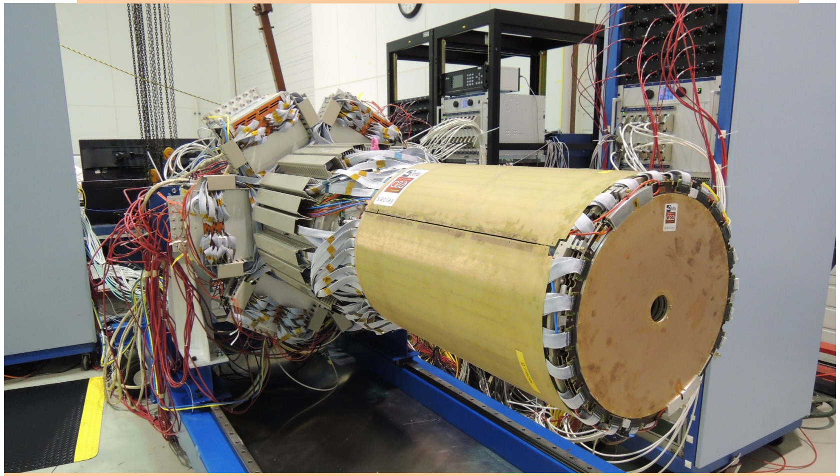
Ring-Imaging Cherenkov (Hadron ID)

CLAS12 Central Detector (Target Region)

High-Threshold Gas Cherenkov (elec. ID)



Central Neutron Detector



Silicon + MicroMegas Vertex Detector

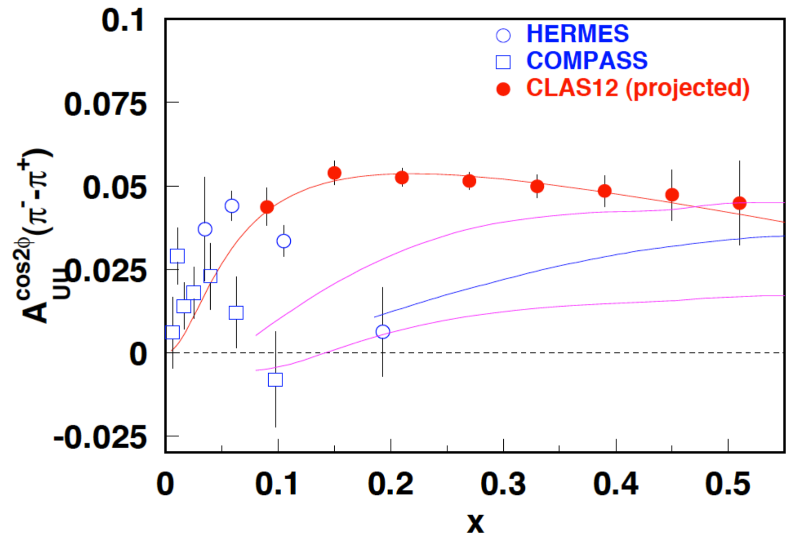
SIDIS Projections

Commissioning with beam since Dec 17

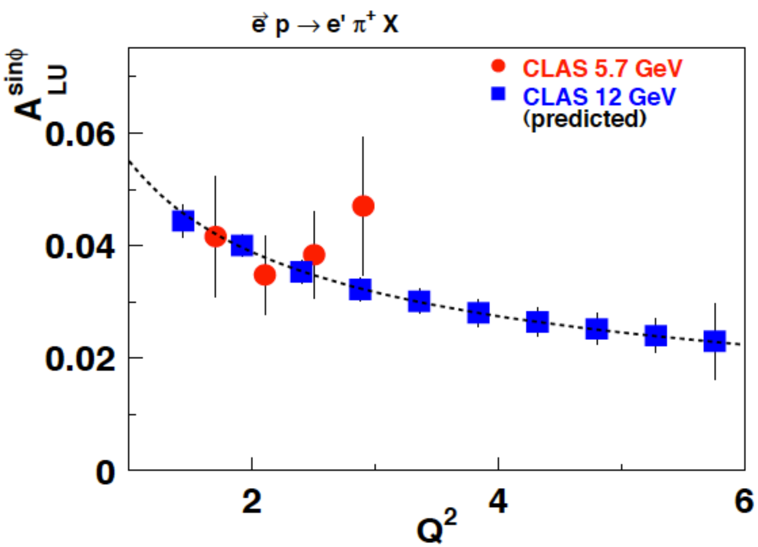
Starting physics data-taking this week

Simultaneous run of all the 4 experimental Halls for the first time

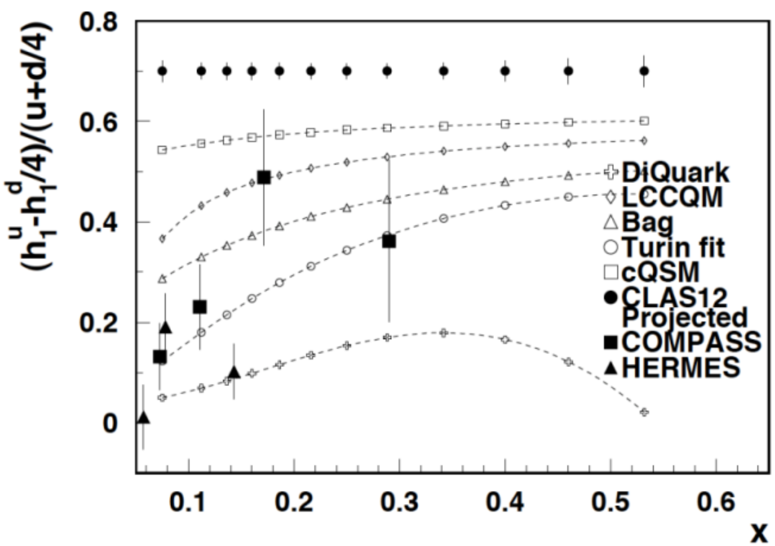
Azimuthal modulations:



Higher twists:

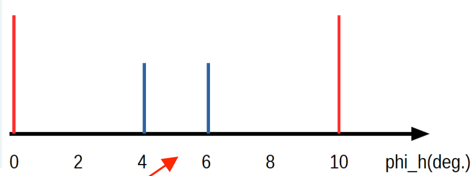


Di-hadron channel:



From Data to Phenomenology

bin#	x	Q^2	y	W	M_X	ϕ	z	P_T	λ	Λ	N(counts)	RC
1 … N												



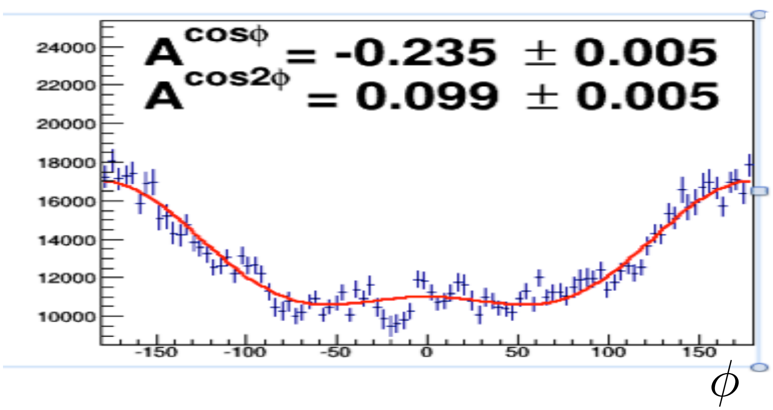
Elementary Bins vs macroscopic bins

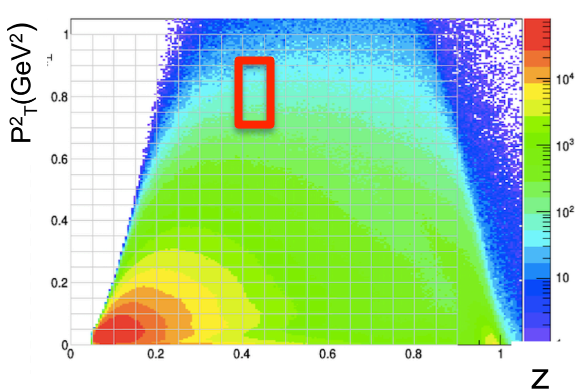
Pros:
1) can go to wider bins
2) smaller bin centering corrections
3) can merge different experiments
4) can perform also Bessel weighting
5) can re-calculate for any other kinematical variables (η,P_T/z,…)

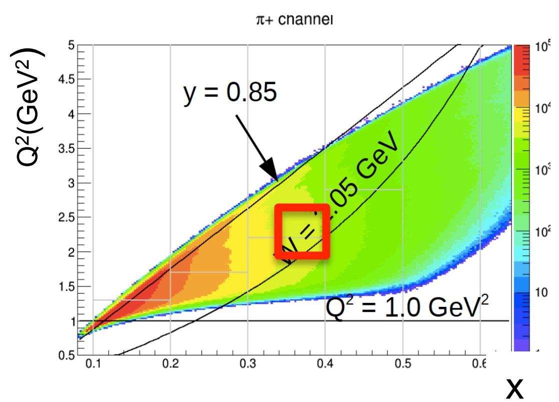
……………………

Cons:
1)Requires huge MC sample

For precision studies of TMDs <u>we need x-sections/muliplicities in smallest possible bins in x,y,z,P_T,ϕ for all hadrons and relevant polarization states</u>

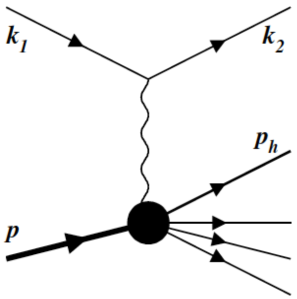






Radiative SIDIS

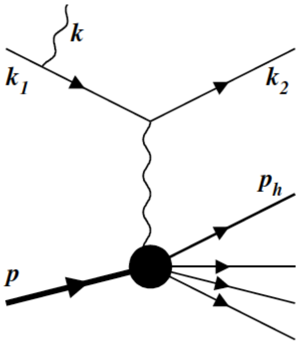
Akushevich&Ilyichev in progress



$$e(k_1,\xi)+n(p,\eta)\longrightarrow e(k_2)+h(p_h)+x(p_x)$$

$$\frac{d\sigma^B}{dx\,dy\,dz\,dp_t^2\,d\phi_h\,d\phi}$$

$$\boxed{d\sigma^B=\frac{\alpha^2}{\sqrt{\lambda_S}Q^4}W_{\mu\nu}L^{\mu\nu}\frac{d^3k_2}{k_{20}}\frac{d^3p_h}{p_{h0}}}$$



$$e(k_1,\xi)+n(p,\eta)\to e(k_2)+h(p_h)+x(\tilde{p}_x)+\gamma(k)$$

$$\boxed{d\sigma_R=\frac{\alpha^3}{4\pi^2\tilde{Q}^4\sqrt{\lambda_S}}W^{\mu\nu}(q-k,p,p_h)L^R_{\mu\nu}\frac{d^3k}{k_0}\frac{d^3k_2}{k_{20}}\frac{d^3p_h}{p_{h0}}}$$

+…..

additional photon can be described by three additional variables:

$$R=2kp,\ \ \tau=\frac{kq}{kp},\ \ \phi_k$$

$$S_x=2p(k_1-k_2)$$

$$\lambda_Y=S_x^2-4M^2Q^2$$

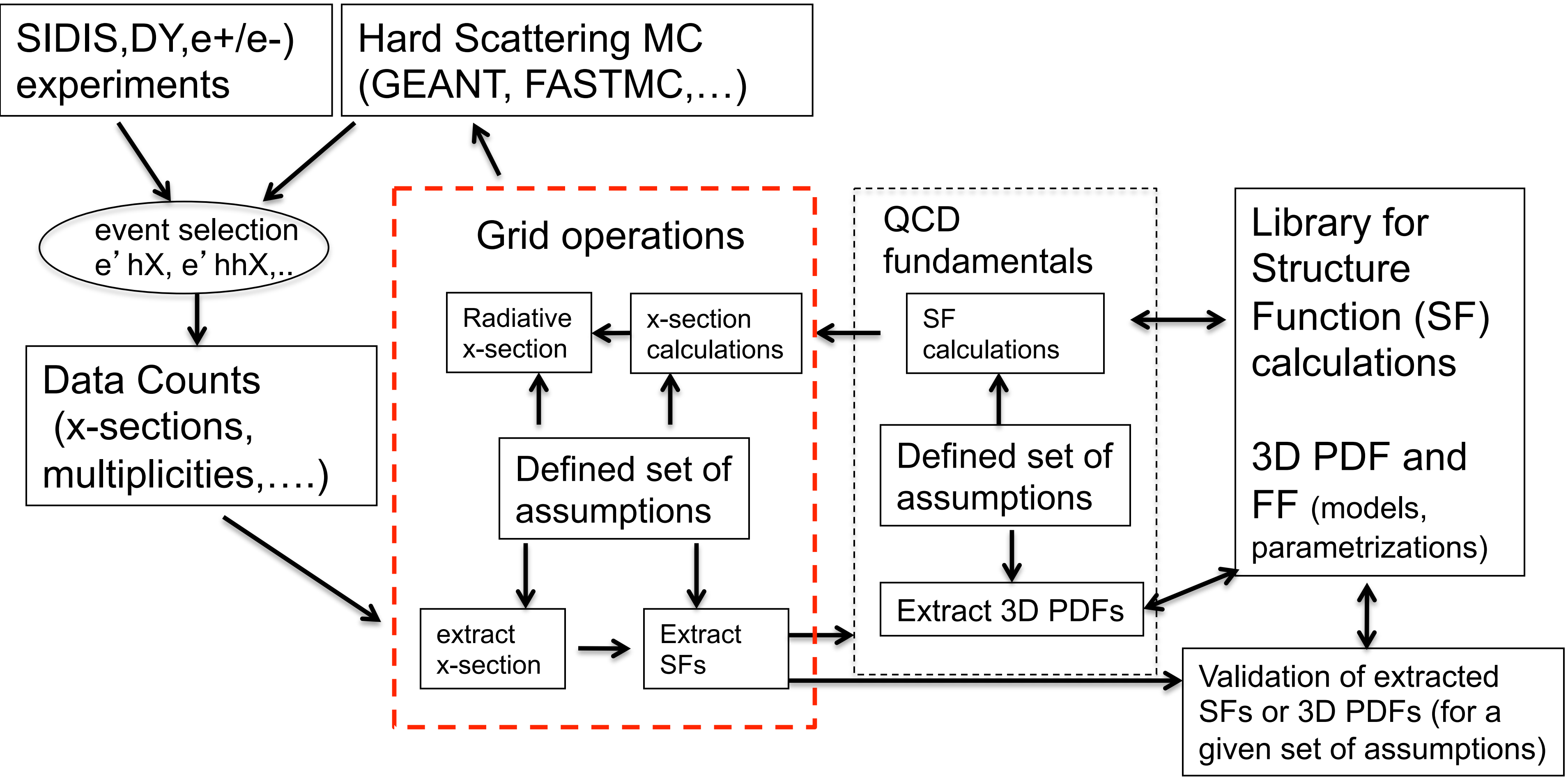
The phase space of the real photon: $\dfrac{d^3k}{k_0}=\dfrac{RdRd\tau d\phi_k}{2\sqrt{\lambda_Y}}.$

ϕ_k is an angle between $(\mathbf{k}_1,\mathbf{k}_2)$ and $(\mathbf{k},\mathbf{q})$ planes.

$$e(k_1,\xi)+n(p,\eta)\to e(k_2)+h(p_h)+u(p_u)+\gamma(k),$$

$$\delta^4(k_1+p-k_2-p_h-p_u-k)$$

3D Extraction and VAlidation (EVA) framework



Development of a reliable techniques for the extraction of 3D PDFs and fragmentation functions from the multidimensional experimental observables with controlled systematics requires close collaboration of experiment, theory and computing

Conclusions

To perform a 3D investigation we need to work in multi-D

binning is only the starting point and implies

- new tools for multi-D systematics approach
- manage stat and sys correlations
- identify proper regime
- new ways of present or exploits the outputs

New facilities anticipates a mess of data
(BELLEII, BESIII, COMPASSII, JLab12, EIC…..)

We have no more excuses but face the challenge!

EVA framework provides a comprehensive approach attempt

Conclusions

BACKUP